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Stability of Asphalt Cement Bound Open-graded Aggregate Layers

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Stability of Asphalt Cement Bound Open-graded Aggregate Layers

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Abstract: The report presents the results of a laboratory study that was carried out to investigate the stability of bitumen–bound coarse single–sized (open–graded) pavement aggregates under dynamic plate loading. All aggregate samples comprised 100% crushed limestone and were constructed over a 100 mm layer of compacted Granular A to simulate a typical field application. The open–graded aggregate was pre–mixed with a bitumen binder to give a maximum asphalt cement content of about 2%. One test was carried out with no binder in order to compare unbound sample performance with bound samples. In order to establish an "equivalency factor" for unbound OGDL layers and Granular A, a single test with a double layer of Granular A comprising 100% crushed limestone was also performed. All plate bearing tests were carried out at room temperature (typically 20° Celsius). Bitumen–bound samples exhibited a bi–linear trend in permanent deformation with the logarithm of accumulated load applications. The deformation plots for these tests were characterized by a pronounced change in slope (expressed as deformation/log number of load applications) after some threshold number of load cycles. The initial slope of the deformation-log number of load applications for AC bound tests was observed to increase with AC content, suggesting that the increased viscosity of the sample due to the bitumen led to accelerated deformation. A conclusion from these tests is that while the inclusion of an AC binder may improve the constructibility of the OGDL material, the long-term (in-service) performance of the layer may be less than the same system constructed without the binder. However, for unbound OGDL materials, the accumulated load-deformation response appears to be "equivalent" to Granular A when materials comprise 100% crushed rock. Based on the results of this test program it is recommended that an "equivalency factor" of 1 be used for unbound OGDL layers constructed to maximum density.

Comments: A final report on R&D project 21189 conducted under the Ontario Joint Transportation Research Programme by the Royal Military College of Canada and Queen's University.

Key Words: pavement materials, granular base, drainage layer, stability

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Executive Summary

The report presents the results of a laboratory study that was carried out to investigate the stability of coarse single–sized (open–graded) pavement aggregates constructed with and without an asphalt cement (AC) binder. Similar materials have been used in trial open–graded drainage layers (OGDL) in Ministry of Transportation of Ontario highway pavements. The OGDL materials had a top size of 19mm and conformed to the MTO specification at the time of the investigation. The compacted OGDL layers were 100mm in depth and one metre square in plan area and were constructed over a 100mm thick layer of compacted aggregate (subbase). The subbase material comprised a 100% crushed limestone with a size distribution conforming to the current specification for MTO Granular A. Up to several million applications of a 40kN load using a 460mm diameter rigid plate were applied to each OGDL sample.

The rigid plate arrangement represents an extreme loading condition that does not model the confined condition that exists for an actual OGDL layer in a highway pavement. The loading arrangement was chosen to ensure an accelerated performance deterioration of trial OGDL materials within a reasonable number of load applications. Hence, conclusions about the *relative* performance of OGDL layers can be drawn from this report. However, the magnitudes of permanent deformations that were accumulated with number of plate load applications are considered to be greatly in excess of the magnitudes that would be anticipated in a similar field pavement structure.

The *relative stability* of OGDL materials having asphalt cement contents ranging from 0% to 2% was established by comparing *rates* of permanent deformation with number of load applications. A single test with a double layer of compacted Granular A was carried out for comparison purposes. All plate bearing tests were carried out at room temperature (typically 20° Celsius). The following observations were made:

- The logarithmic rate of accumulated plastic deformation was observed to increase with asphalt cement content. The most stable samples were those compacted without an AC binder.
- Unbound samples exhibited a linear deformation trend with the logarithm of the number of load applications. In contrast, samples constructed with an AC binder showed a distinctive bi–linear trend with a pronounced increase in the logarithmic rate of permanent deformation after a threshold number of load applications.
- The threshold number of load applications after which the logarithmic rate of deformation was observed to increase was seen to diminish with increasing AC content.

- The unbound samples of OGDL material showed (semi-log) deformation rates that were similar to that measured in the single (control) test constructed with a double layer of Granular A.

A conclusion that can be drawn from these tests is that an AC binder may improve the constructability of the OGDL material but the long-term (in-service) performance of the layer may be less than the same system constructed without the binder. In other words, the viscosity of the bitumen binder in combination with the thin particle coating may in fact increase the mobility of the aggregate under long-term repeated loading. Another important conclusion that can be drawn from the data is that the response of the unbound OGDL material is "equivalent" to the same thickness of compacted Granular A when both materials are 100% crushed rock. Hence an "equivalency factor" of 1 for OGDL layers constructed to maximum density and without a bitumen binder may be assumed in pavement design.

Acknowledgements

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1/ Introduction

The infiltration of surface water into pavement cracks and joints is a major source of pavement deterioration in highway pavements. A strategy to reduce or eliminate this problem is to construct an open-graded drainage layer (OGDL) directly below the surface course that is connected to shoulder drains (e.g. Baldwin and Long 1988, Highlands and Hoffman 1988, Engineering News Record 1979, Cedergren 1988). An example of a highway pavement structure that incorporates an OGDL is given in **Figure 1**. In practice, the OGDL is often connected to trench drains or geocomposite edgedrains constructed within the pavement shoulder. A successful OGDL must be capable of removing water at a rate greater than the infiltration rate. In general, OGDLs are made of essentially single-sized aggregates. They must be protected by filters to prevent plugging and connected to positive drainage outlets. The influence of grain size distribution on aggregate permeability in pavement structures has been the topic of investigation by many researchers (e.g. Highlands and Hoffman 1988, Cedergren et al. 1973, Moyanhan and Sternberg 1977, Smith et al. 1965, Strohm et al. 1967). However, because of their proximity to the pavement bearing surface they should also possess adequate stability against traffic-induced shearing stresses. These shearing stresses may be further amplified in the vicinity of pavement cracks (or joints in the case of reinforced concrete pavements) that can result in over-stressing of the OGDL materials. The necessity of providing both adequate drainage capacity and adequate stability are conflicting requirements since stability generally increases with increased particle size distribution while drainage increases with increasing voids. It is common practice to add a 1.5% to 2% asphaltic cement (AC) binder to stabilize the layer during construction activities. The AC content should be just great enough to coat the aggregate and not reduce permeability of the material. Nevertheless, unbound open-graded drainage layers have also been successfully constructed as reported by Highlands and Hoffman (1988) and Engineering News Record (1979). In a previous investigation (e.g. Bathurst and Raymond 1990a,b) the influence of aggregate properties on the stability of *unbound* OGDL samples constructed in the laboratory has been reported. This previous related work was carried out under R&D Project 21164 of the Ontario Joint Transportation Research Programme. The laboratory investigation described herein is a continuation of the earlier investigation by the authors and examines the influence of aggregate density and bitumen content on the stability of asphalt cement-bound OGDL layers constructed over compacted Granular A layers. Concurrent with the laboratory investigation, the authors and MTO personnel have carried out an investigation of the field performance of open-graded drainage layers at trial OGDL installations on MTO highway pavements (Hajek et al. 1991).

2/ Current Experience at MTO

Ministry of Transportation of Ontario (MTO) specifications for OGDL materials have not been finalized at the time of this report. Trial installations dating back to 1975 (Hajek et al. 1991) have relied on in-house experience with the performance of traditional aggregates and asphalt mixes that use existing aggregate gradations. At the present time pavement structures in Ontario that incorporate an OGDL have not undergone long-term laboratory testing or evaluation. The field performance of existing OGDLs shows that the modified mixes are prone to stripping and settlement in the vicinity of transverse cracks (e.g. Bathurst and Raymond 1991, Hajek et al. 1991). This has been attributed to water penetration, stripping of asphalt cement and the pumping action that may result from traffic loading. It is expected that stripping and settlement of the OGDL can occur with time due to the thin asphalt coating and low initial void ratios achieved during construction. This may occur particularly at the pavement joints and cracks where water penetration is increased and the potential for pumping is largest. An important conclusion that can be drawn from these observations is that the stability of an OGDL in the vicinity of pavement cracking is ultimately controlled by the inherent stability of the stripped aggregate.

3/ Scope Of Current Investigation

This report describes a laboratory investigation that was carried out to examine the influence of density and the magnitude of AC content on the stability of AC-bound open-graded drainage layer samples under simulated traffic loading. The samples were constructed over a layer of compacted Granular A aggregate.

The laboratory work reported here was carried out concurrent with an investigation program that examined the field performance of trial OGDL pavements at several highway sites in Ontario. The results of this complimentary field work have been reported by Bathurst and Raymond (1991) and Hajek et al. (1991).

4/ Test Program

4.1/ General

The test program was focussed on the mechanical stability of samples of OGDL aggregate placed and compacted over a thin layer of compacted Granular A.

The relative stability of the aggregate materials was determined by comparing the cumulative load–deformation response measured at the surface of the two–layer systems during repeated loading in a laboratory plate loading apparatus. The variable between samples was the asphalt cement (AC) content. Experience from similar test programs on the stability of railway ballast and an earlier related investigation by the authors has shown that the compressibility of the underlying structure has a very important influence on the cumulative load–deformation response of aggregate materials (Raymond and Bathurst 1987, Bathurst and Raymond 1990a,b). Therefore, in order to simulate a typical field condition, the OGDL material were prepared over a thin layer of compacted Granular A. The properties of the aggregates used in the study are given in **Table 1** and a summary of test configurations is given in **Table 2**. The report is concerned primarily with the results of 16 plate bearing tests that used variable AC content in the OGDL mix (i.e. 0 to 2% AC content). One additional test was carried out using a double layer of Granular A material to examine the relative stability of unbound OGDL materials with respect to Granular A materials under identical loading conditions. All plate bearing tests were carried out at room temperature (typically 20° Celsius).

4.2/ Plate Bearing Test Procedure

The general arrangement for the plate bearing test is given in **Figure 2**. An overview of the test system is shown in **Figure 3**. The OGDL is modelled as a layer of aggregate 100 mm thick and is supported by a 100mm thick layer of compacted Granular A. The two layer structure is illustrated in the photograph on **Figure 4**. The 100 mm thickness is typical of OGDL installations in Ontario and in the United States (Baldwin and Long 1988, Ministry of Transportation of Ontario communication). Nevertheless, 100mm is likely the minimum thickness that would be considered in actual installations in order to facilitate construction and to ensure adequate flow capacity. The OGDL samples were one meter by one meter in plan area and laterally confined by a rigid timber and steel framework. The sample walls and aluminium bottom were bolted to a 25mm thick steel plate cemented to the floor of the laboratory. The tray permits unbound aggregate samples to be placed and compacted away from the loading system.

A sinusoidal loading pulse with an amplitude of 2 to 40kN was applied to the surface of each sample using a 457mm diameter rigid steel plate. The maximum 40kN load represents

a standard half-axle load. The 457mm diameter plate (as opposed to say a 300mm diameter plate) was selected in order to simulate the increased bearing area that would exist in the pavement structure at the elevation of the OGDL as a result of vertical load spreading through a relatively thin overlying surface course. The minimum load level of 2kN was selected to ensure that there was a good contact between the aggregate and the loading plate at all times. Nevertheless, the rigid plate arrangement represents an extreme loading condition that does not model the confined condition that exists for an actual OGDL layer in a highway pavement. However, it should be noted that the loading arrangement was chosen, in part, to ensure an accelerated performance deterioration of trial OGDL materials within a reasonable number of load applications and therefore allow conclusions to be drawn with respect to the *relative* performance of OGDL samples.

The load was delivered to the plate using an MTS (Materials Testing Systems) closed-loop electro-hydraulic actuator controlled by a DEC PDP11/34 computer. A load cell and linear variable displacement transducer (LVDT) located above the actuator base were used to monitor footing loads and vertical displacements. At programmed intervals, the load-deformation response of the footing during a loading cycle was recorded and stored by the computer. The load was applied at a rate of 5Hz for up to 11.1 million load applications or until 20mm of permanent vertical deformation at the loading plate occurred. The plate was maintained in a horizontal position throughout the test by passing the actuator piston through a rigidly-supported Teflon bushing (Bathurst and Raymond 1990).

4.3/ Aggregate

The aggregate materials used in this investigation comprised 100% crushed rock. Both the Granular A and OGDL materials were limestone materials obtained locally. The grain size distributions for the aggregate materials are given in **Figure 5**. The gradation for the open-graded material conforms to a typical MTO OGDL specification in use at the time of the current investigation. The target OGDL gradation was achieved by blending pre-sieved aggregate size ranges taken from laboratory stock piles.

4.4/ Preparation of Granular A sample

The Granular A subbase layer was placed and compacted to a depth of 100mm within the 1m x 1m box illustrated in **Figure 2**. The aggregate was compacted dry using a 10kN BOMAG double drum vibrating compactor. The density of the compacted aggregate was 2069 +/- 72 kg/m^3 (**Table 2**). The density of the aggregate was determined from a mass-volume calculation of the contents of the 100mm lift of subbase material. After subbase preparation, the sidewalls were extended vertically another 100mm prior to placement and compaction of the OGDL aggregate.

4.5/ Preparation of Bitumen Bound OGDL Test Specimens

The AC bound OGDL materials were prepared as a hot mix using a BOMAG (asphalt recycler) hot drum mixer (**Figure 6**). The drum was charged with 180 kg of OGDL aggregate and heated to about 140 degrees Celsius using a propane torch. The bitumen binder (85–100 penetration) was pre-heated and then added to the OGDL aggregate once the contents of the drum had achieved the desired temperature. The drum was rotated until a uniform coating of AC was achieved over all aggregate particles. The contents of the drum were then poured into the sample tray over the previously prepared subbase layer. The OGDL mix was raked level and then transported using a roller system to a specially constructed ramp for compaction (**Figure 7**). Once the aggregate had cooled to about 60–70 degrees Celsius the OGDL was rolled and compacted using a 10kN BOMAG double drum vibrating compactor. A total of four Marshall samples of OGDL materials were made at the time of each OGDL batch. The AC content for bound OGDL samples was determined using the method of test in ASTM D 2172.

The properties of the OGDL mixes after compaction are summarized in **Table 2**. The same total mass–volume procedure used to calculate the density of the subbase was used to calculate the density of the as–compacted OGDL. The measured density of the OGDL samples after compaction has been plotted against measured AC content on **Figure 8**. The average compacted density of the samples was 1867 kg/m^3 but varied from 1707 to 2079 kg/m^3. It should be noted that the compaction densities achieved for these laboratory samples varied over a wide range but included the range of densities measured in the field as part of the companion study on the performance of trial OGDL materials in MTO highways (Bathurst and Raymond 1991, Hajek et al. 1991). At two highway sites where a total of 13 AC–bound OGDL cores were retrieved intact, the density of the OGDL was found to vary from 1791 to 1894 kg/m^3. The wide variability in the measured density of laboratory manufactured samples (even for samples prepared at nominal similar AC contents) can be attributed to (i) segregation of the sample during mixing (ii) autogenous grinding of the aggregate during mixing and crushing of aggregate particles during compaction, and (iii) variability in sample temperature during compaction. While the influence of density of AC mixes on performance was an initial objective of the test program reported here, the difficulty in controlling the density of large AC mixes precluded a systematic investigation of this variable. However, as the data on **Figure 8** illustrates, the as–constructed density of laboratory–manufactured samples includes the range of as–constructed densities measured from field samples.

The target AC content for the tests varied from 0 to 2%. However, the results of AC content analyses performed on bulk OGDL samples at the completion of repeated loading showed that the AC contents for bitumen bound tests fell within the range 0.78 to 1.74%. The variability of AC content within the samples was also evident from measured AC contents taken from Marshall samples. The as-measured AC contents proved to be higher than target values. This is likely due to the presence of a residual bitumen coating on inside of the drum mixer. The AC contents determined from Marshall samples (**Table 2**) are generally greater than those determined from larger bulk samples. This is likely due to the the observation that the Marshall samples were taken from the mixer after pouring the OGDL and particles appeared to be somewhat larger due to segregation and more thickly coated due to contact with residual bitumen on the drum walls. Nevertheless, the AC contents summarized in **Table 2** are typical of values measured in intact cores taken from trial field installations (Bathurst and Raymond 1991). The test results reported herein are referenced to the AC contents determined from bulk samples of the OGDL aggregates taken at the end of repeated loading.

All plate loading tests were carried out within 10 days of sample preparation. **Figure 9** shows a close up view of the loading plate after repeated loading of a bitumen-bound OGDL sample. The large permanent deformation evident in the photograph is typical of tests with high AC contents. These tests were usually terminated within a relatively small number of load applications once 20mm of vertical deformation was recorded (e.g. less than one million load applications).

5/ Test Results

5.1/ Performance of OGDL Aggregates under Repeated Loading

The results of selected plate bearing tests with OGDL aggregates having a range of AC binder content are illustrated in **Figures 10a** and **10b**. **Figure 10a** shows that the cumulative (permanent) displacement with number of load repetitions is highly non-linear with most of the deformation occurring early in the loading program. Nevertheless, the trend in the selected data is that the amount of permanent deformation after the same number of load applications increases with the magnitude of AC content. The same data are repotted with semi-logarithmic axes in **Figure 10b**. The data for the unbound sample shows that the permanent displacements vary linearly with the log number of load applications. This response is in agreement with previous qualitative results reported in an earlier laboratory investigation by the authors that focussed on the performance of unbound OGDL aggregates under similar loading conditions (Bathurst and Raymond 1990). The trend in the data on **Figure 10b** for bound OGDL samples is qualitatively different from the unbound samples since there is a *bi-linear* trend in the plotted data. In other words there is a threshold number of load applications after which the rate of accumulated deformation with log number of load applications actually increases.

Permanent deformation as a relative measure of aggregate stability under load can be misleading since the magnitude of permanent deformation after a given number of load applications is sensitive to the effect of initial plate seating. In this investigation the most reliable measure of relative stability between AC bound tests was described by two parameters denoted as m and N_b:

(1) Parameter m is measured as the rate at which permanent deformation is accumulated with respect to the log number of load repetitions N taken over 10 to 10^4 load applications (i.e. units of mm/log cycle number of load applications).

(2) Parameter N_b is the number of load applications to achieve the breakpoint in permanent deformation-log N plots.

For brevity in the following text, the quantity m is referred to as *deformation rate*.

Calculated values of deformation rate from all OGDL tests are summarized on **Figure 11**. The figure illustrates that in general there is an increase in deformation rate with increase in AC content. The effect of adding a 2% bitumen binder to an OGDl layer is to increase the deformation rate by a factor of 1.5 to 6 over the early portion of the loading history.

The number of load repetitions to the breakpoint in the semi-logarithmic plots for bound OGDL tests is summarized in **Figure 12**. The unbound samples did not exhibit a bi-linear

deformation–log N trend and therefore results from samples with 0% AC are not plotted. However, based on the data plotted and the results of unbound tests, it is reasonable to expect that there would be a highly non–linear trend in the N_b versus AC content data if tests had been carried out with AC contents less than (say) 0.5%. Nevertheless, the available data does plot within a narrow band as illustrated in the figure. The top of the shaded envelope illustrates that the number of load applications before sample failure defined by N_b can be increased by a factor of 4 by reducing the AC content from 1.5% to (say) 0.75%. Based on the interpretation of results given in **Figures 11** and **12** it appears that the lower the AC content the more stable the OGDL layer under repeated loading.

5.2/ Double Layer Granular A Test

A single test with a double layer of dry Granular A was carried out for comparison purposes. The density of the top 100mm of this 200mm thick sample was 2165 kg/m^3 which was the greatest density of any sample in the test program. Greater densities for the Granular A as compared to the OGDL materials in this study can be anticipated since the former has a broader size distribution.

The results of permanent deformation measurements versus log number of load applications for OGDL samples and the Granular A test are illustrated in **Figure 13**. The figure shows that both sample types exhibit essentially linear increases in permanent deformation with the logarithm of the number of load applications. The deformation rate for the unbound OGDL layer varies by a factor of 1 to 2.5 times the deformation rate of the control sample. Within experimental error it is reasonable to assume that the dry well–compacted OGDL materials in this investigation are sensibly equivalent in deformation behaviour to similar depths of dense compacted Granular A.

5.3/ Additional Tests

A total of 9 Marshall test samples were taken during the preparation of AC–bound OGDL mixes. These samples were used to confirm bulk densities determined from mass–volume calculations on the entire OGDL mix and to check AC content test values performed on samples excavated from OGDL specimens after repeated loading.

Modified Marshall stability tests were carried out on the samples. However, the results of these tests were inconclusive since the samples were very unstable due to the low bitumen content. The stability and flow numbers determined from the few samples that did remain intact did not show any systematic dependence on AC content.

6/ Conclusions

The results of the current laboratory investigation have shown qualitative relationships between aggregate stability under dynamic loading and bitumen content. The coarse open–graded aggregate that was investigated conformed to a typical particle size distribution recommended by MTO at the time of the study. The test samples were constructed over a subbase layer of compacted Granular A. The OGDL–Granular A sequence of layers is typical of many trial OGDL installations in Ontario.

The test results illustrate that the *relative stability* of the OGDL layers diminishes with increasing asphalt cement content. The relative stability of the test samples was determined in part by measuring the rate of permanent deformation with the logarithm of the number of load applications. This deformation rate was observed to increase with increasing bitumen content and this is due to the thin particle coating and viscosity of the asphalt binder. In other words, as bitumen content increases, the mobility of the single–sized OGDL materials under repeated load increases.

It should be noted that no conclusions are drawn in this report with respect to the *magnitude* of permanent deformation after a given number of load applications that may be expected in the field for a nominally identical highway pavement because the laboratory loading arrangement represents an extreme condition. The small number of load applications (i.e. less that 1 million) that was observed to generate excessively high permanent deformations of the order of 20mm in some tests is the result of: (a) lack of OGDL confinement, (b) high bearing pressures, (c) the rigid plate and, (d) testing temperature of 20° Celsius.

A preliminary conclusion from these tests is that while the inclusion of an AC binder may improve the constructability of the OGDL material, the long–term (in–service) performance of the layer may be less than the same system constructed without the binder.

A final conclusion that can be drawn from the data presented is that the response of the unbound OGDL is "equivalent" to Granular A. A preliminary recommendation would be to assign an "equivalency factor" of 1 for unbound OGDL layers constructed to maximum density.

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Table 1: Summary of Aggregate Properties

Aggregate Type•	Specific Gravity	Mill Abrasion (MA) %	Los Angeles Abrasion (LAA) %	I_a	C_u	C_c
OGDL Dibble Limestone	2.68	9.1	28.9	74	2.5	1.2
Granular A (Limestone)	2.68	–	–	–	21	2.4

Aggregate Index Number $I_a = 5 \times MA + LAA$; Coefficient of Uniformity $C_u = D_{60}/D_{10}$
Coefficient of Curvature $C_c = D_{30}D_{30}/D_{60}D_{10}$
• all aggregates 100% crushed rock

Table 2: Summary of Tests

Test No.	Granular A subbase density (kg/m^3)	OGDL density (kg/m^3)	OGDL AC content (%) (bulk)	(Marshall)	Number of load applications
40	2015	1921	1.29		390000
41	2010	1990	1.58		1130000
42*	2042	N/A	N/A		5130000
44	2010	1798	0		11100000
45	2047	2079	1.43		350000
46	2124	1992	1.48		210000
47	2041	2078	0		2140000
48	2068	1883	1.13		330000
49	2122	1808	1.70		100000
50	2026	1841	0		1236000
51	2054	1924	1.59	(1.81)	160000
52	2142	1813	0.87	(1.17)	3320000
53	2109	1802	1.74	(1.65)	90000
54	2081	1736	1.31	(1.46)	50000
55	2078	1765	1.65	(2.00)	250000
56	2085	1811	1.16	(1.48)	350000
57	2063	1825	1.20	(1.18)	410000
58	2081	1833	0.78		1560000
59	2094	1858	1.31	(1.41)	600150
60	2091	1765	1.29	(1.34)	100050

* double layer of compacted Granular A

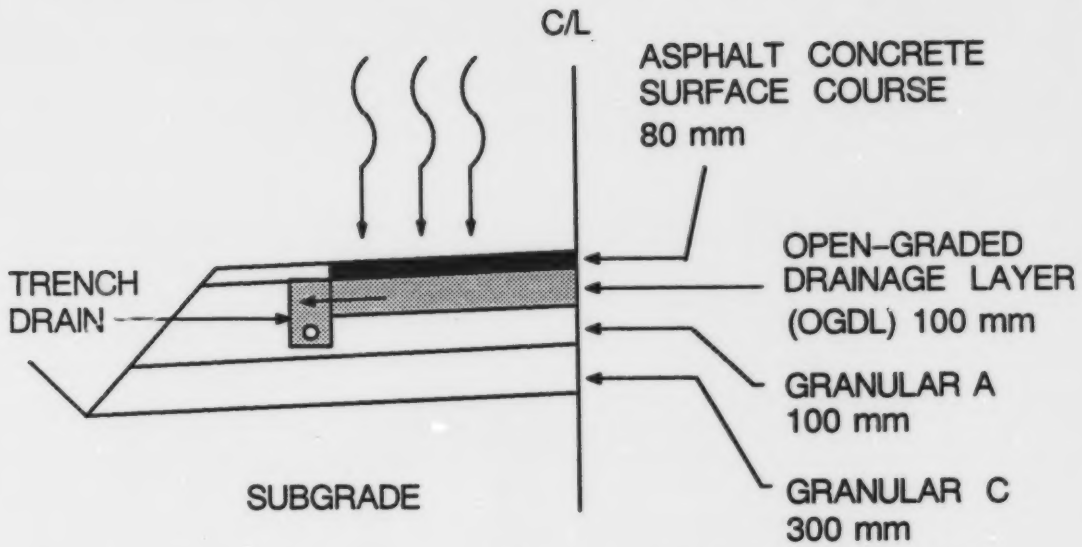


Figure 1 Concept of highway pavement with open-graded drainage layer (OGDL)

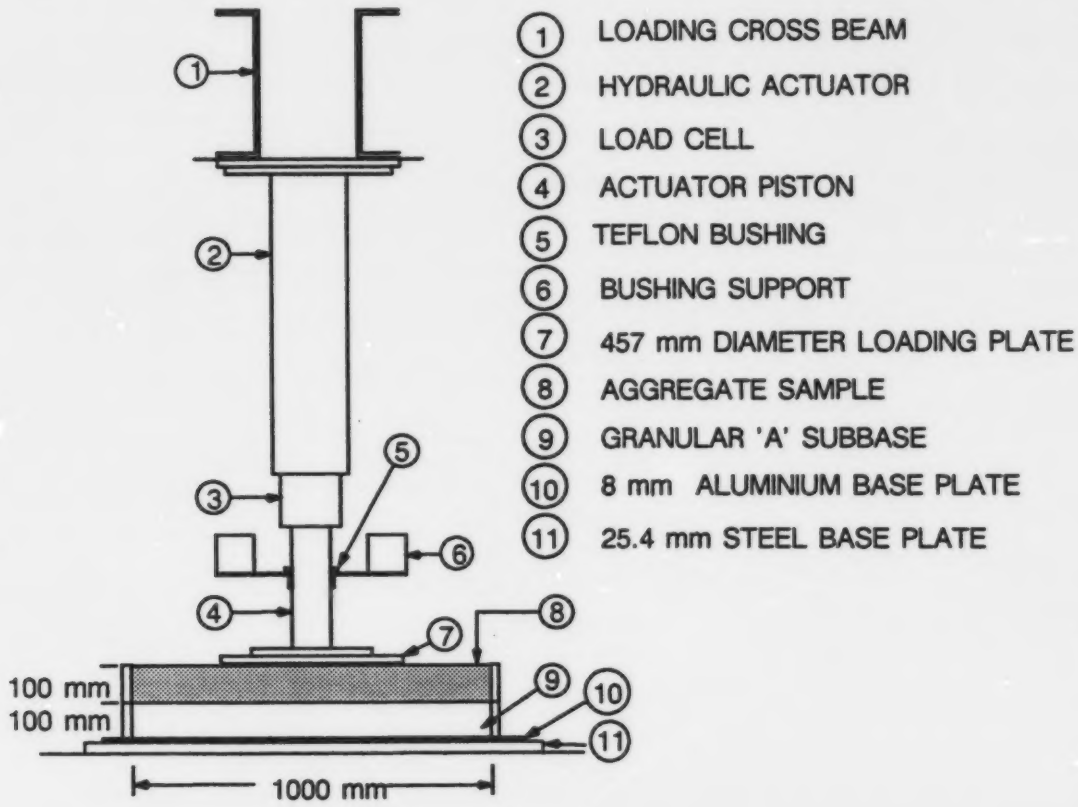


Figure 2 Plate loading apparatus

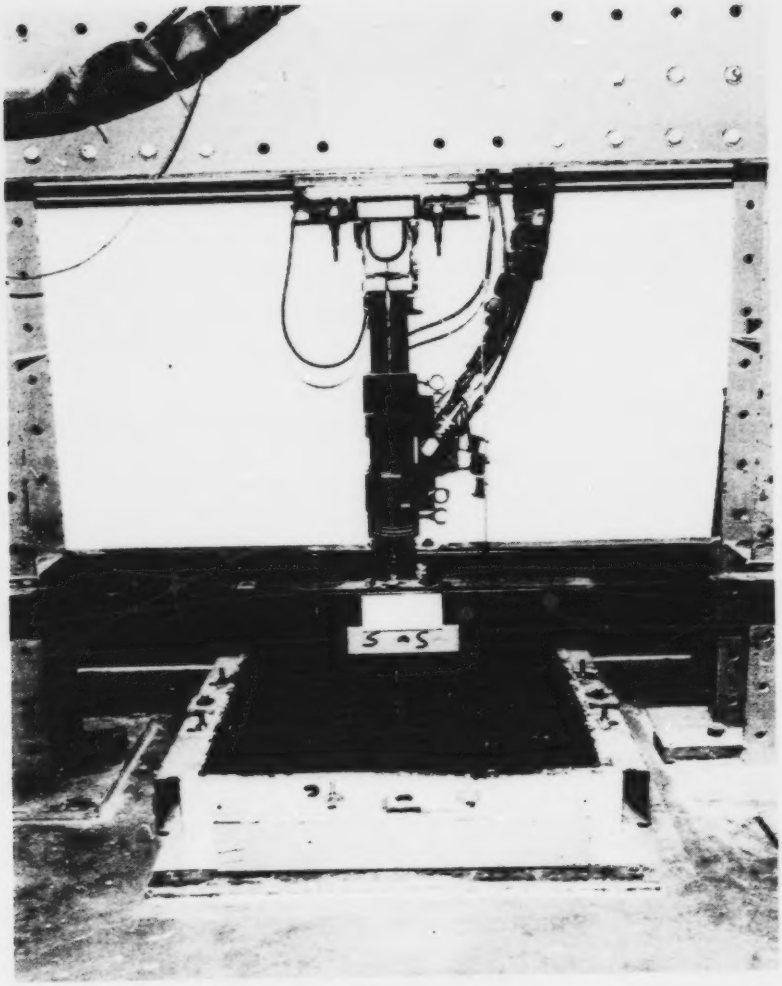


Figure 3 Overview of plate loading apparatus

Figure 4 Excavated test sample after repeated loading

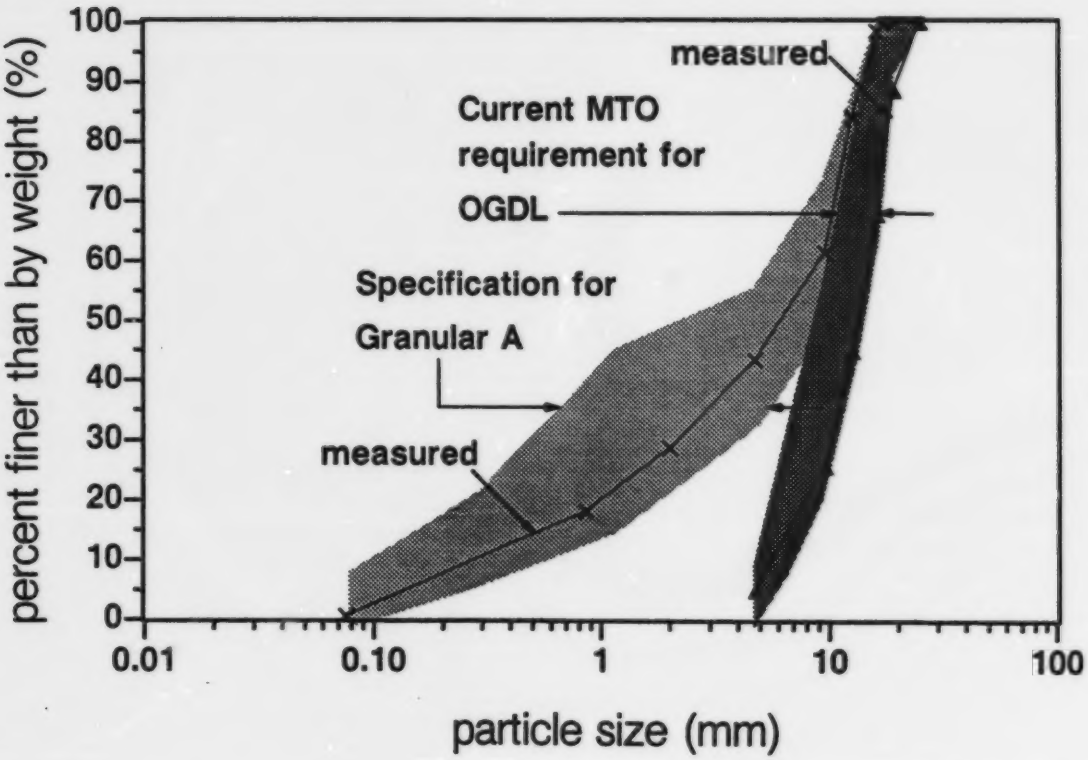


Figure 5 Grain size distribution curves for aggregate materials

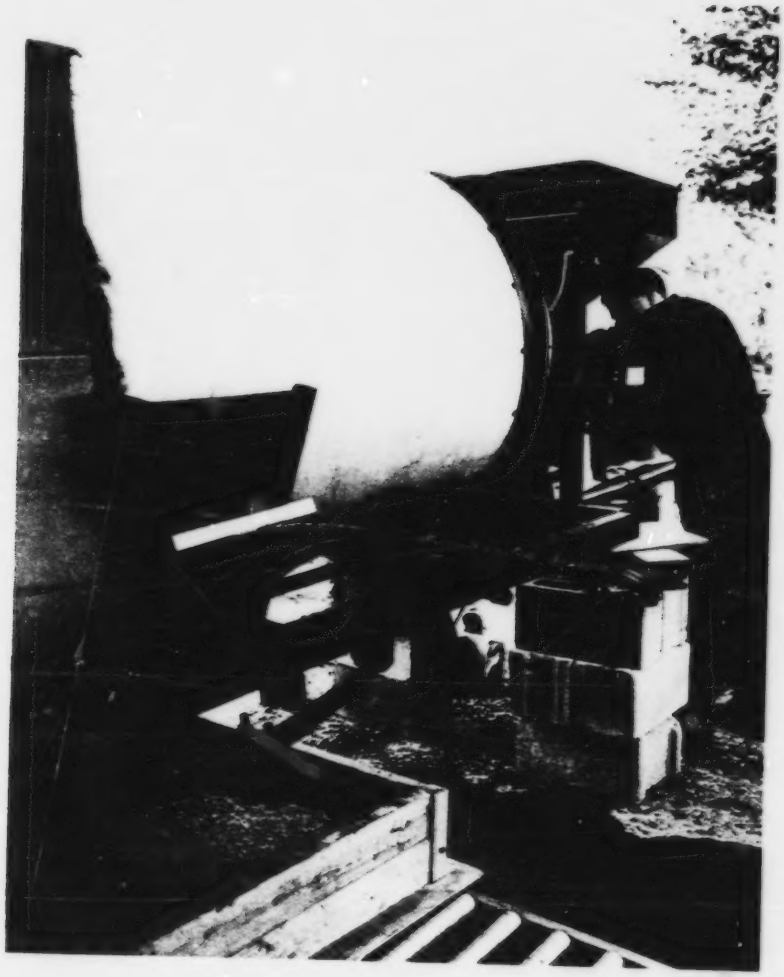


Figure 6 BOMAG Asphalt Recycler

Figure 7 Compaction of OGDL–Granular A samples

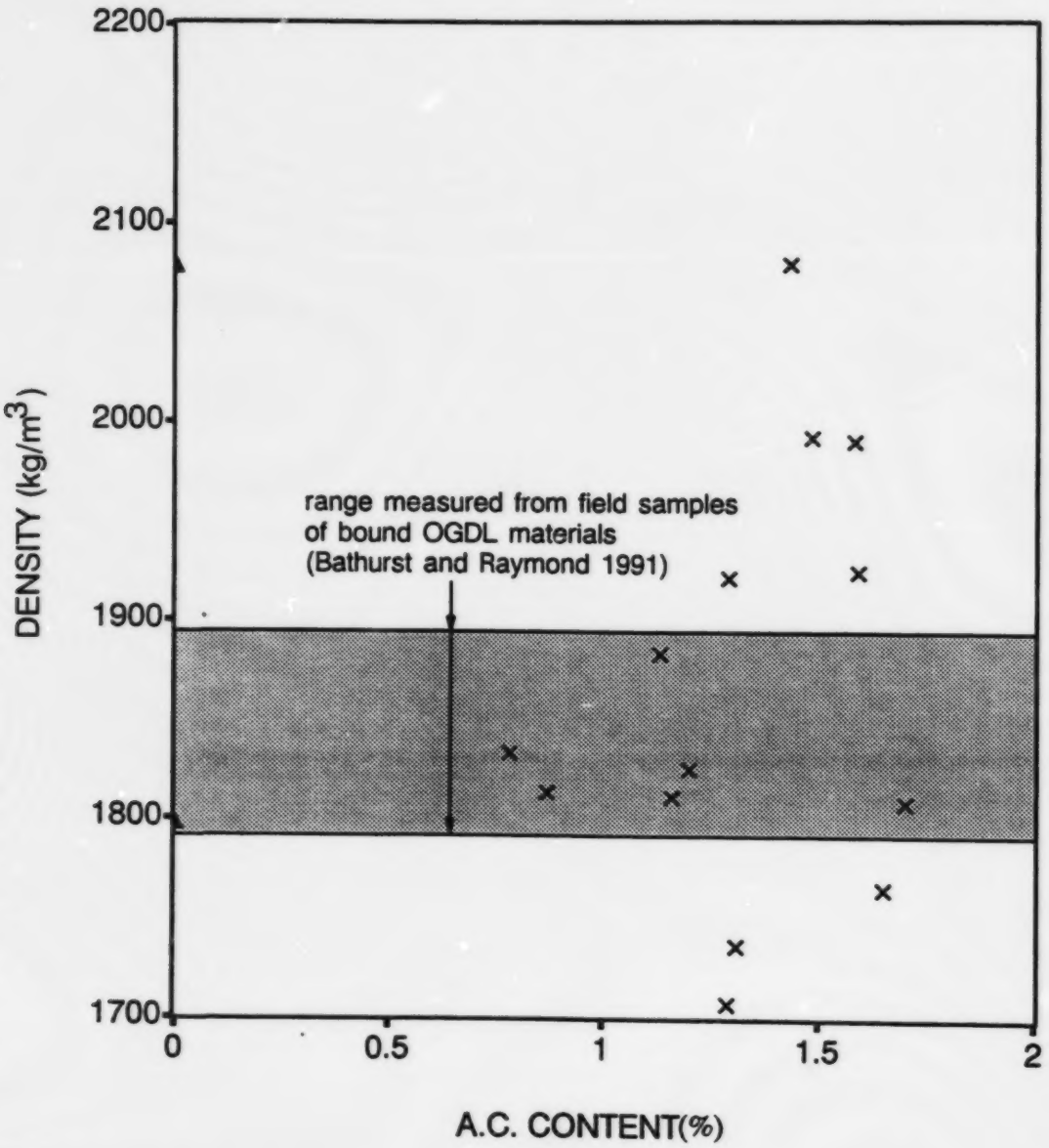
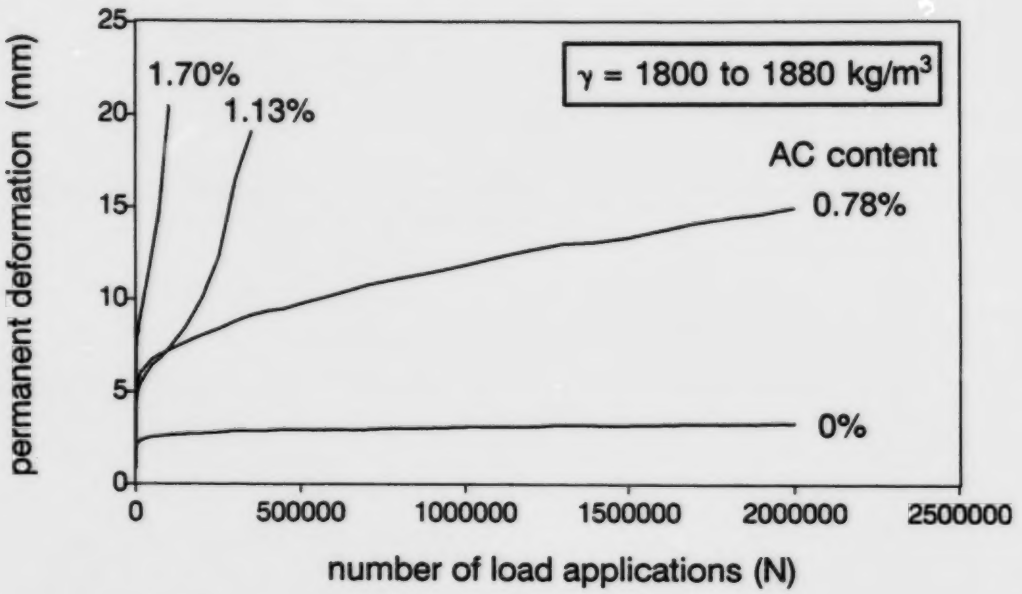
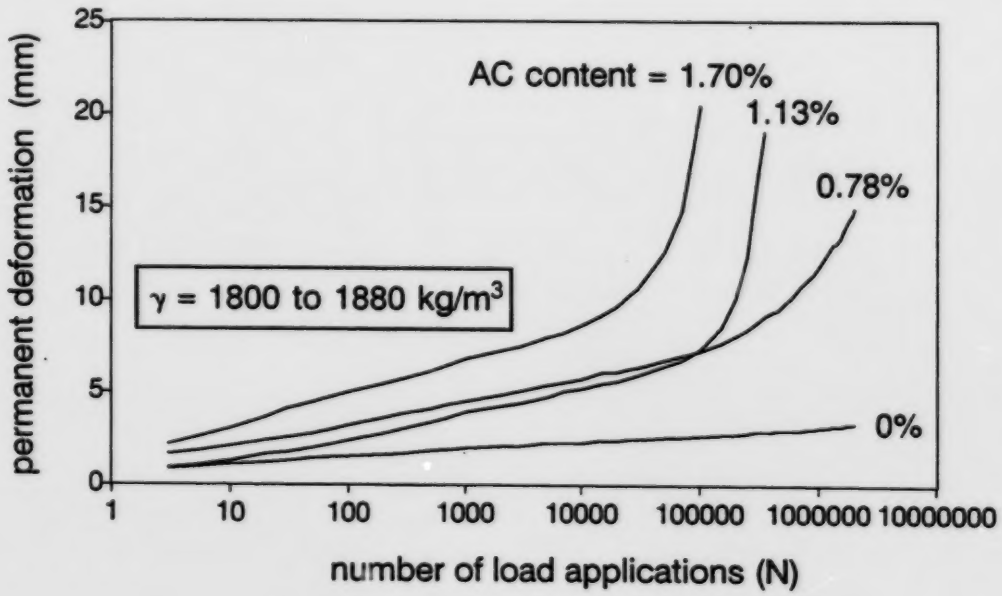


Figure 8 Density of compacted laboratory OGDL materials versus AC content

Figure 9 View of surface deformation at the end of repeated loading for AC bound OGDL sample



a) linear scale



b) semi-log scale

Figure 10 Permanent deformation versus number of load applications for tests with Granular A subbase

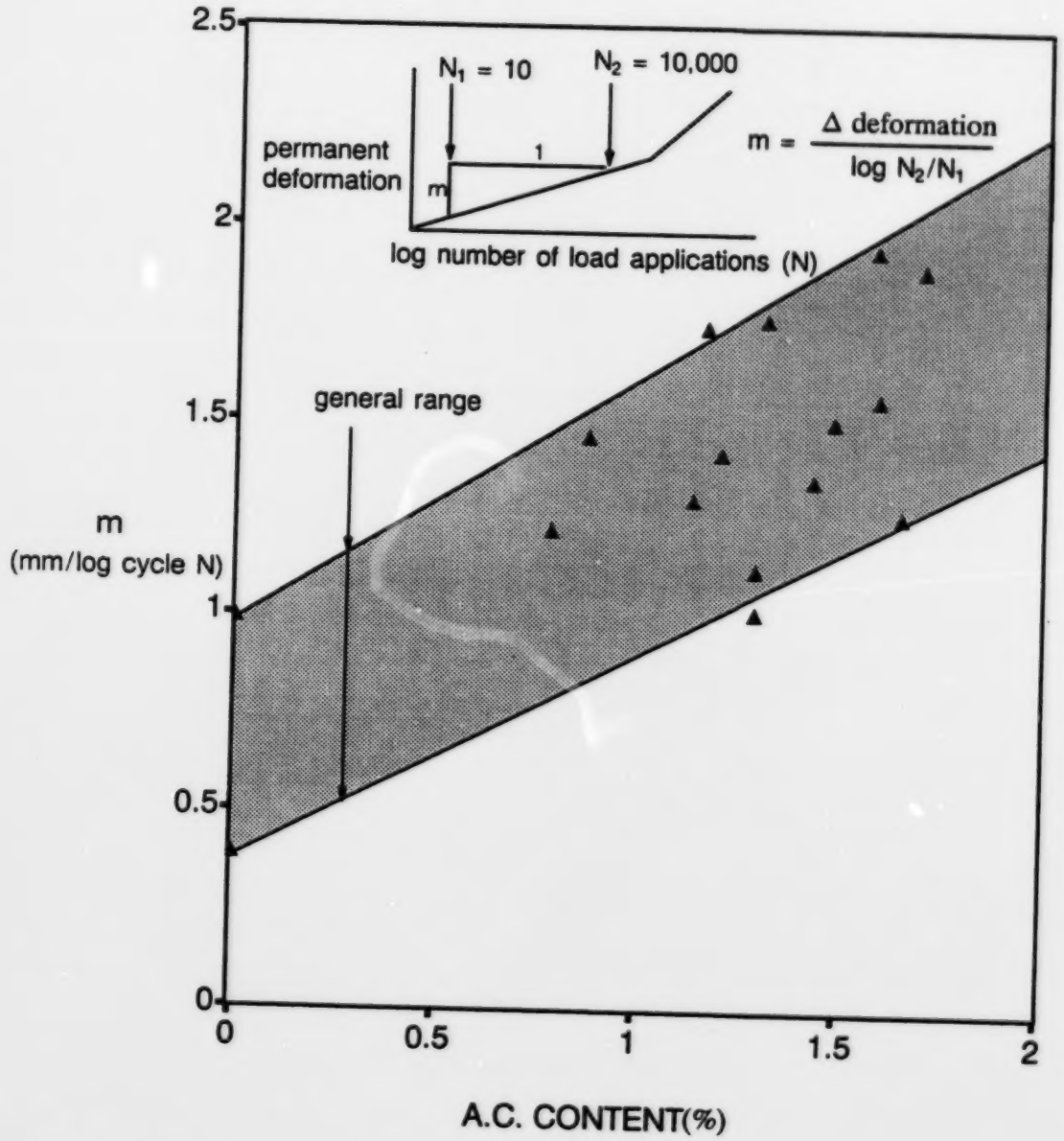


Figure 11 Deformation rate (m) versus AC content

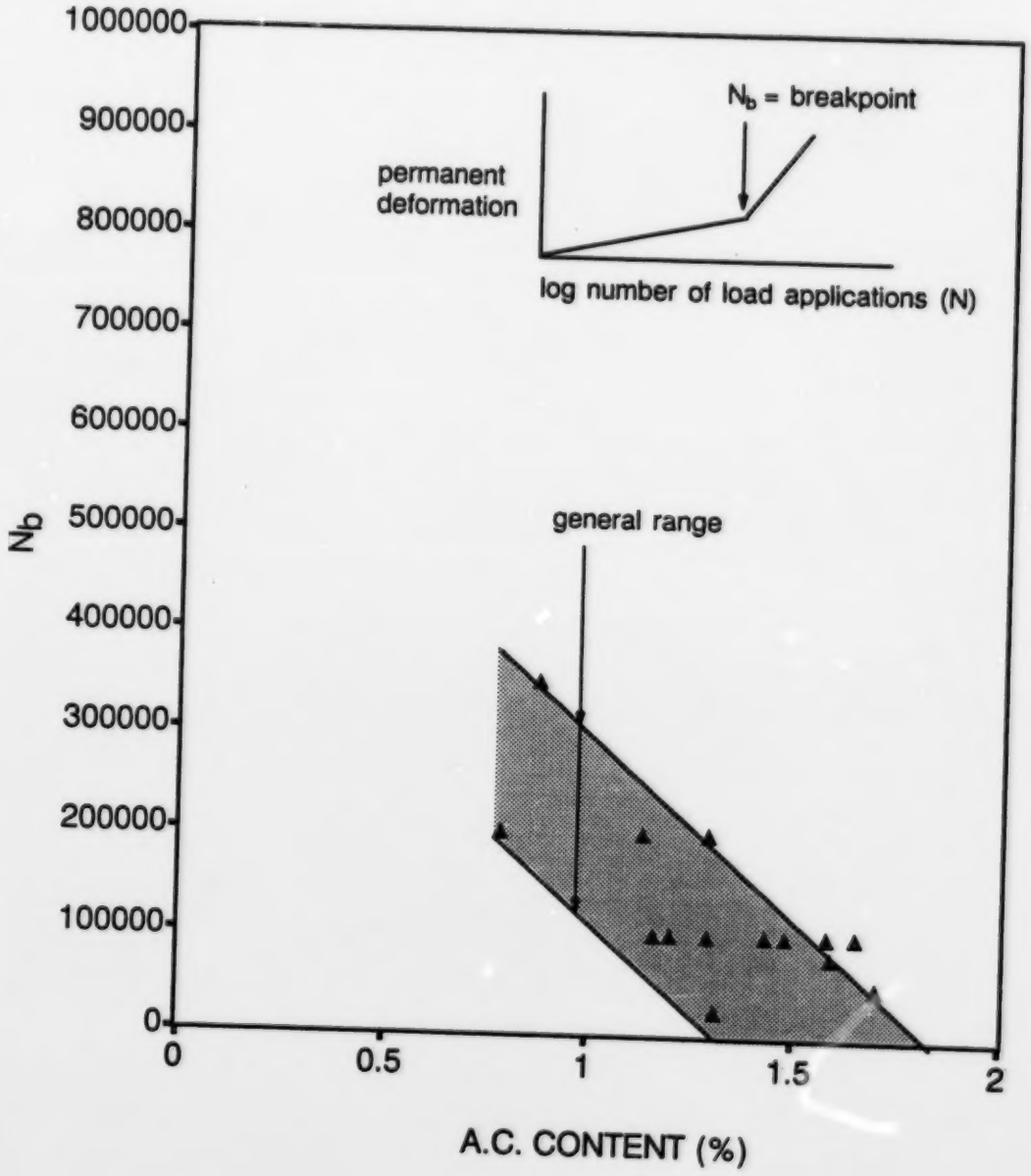


Figure 12 N_b versus AC content

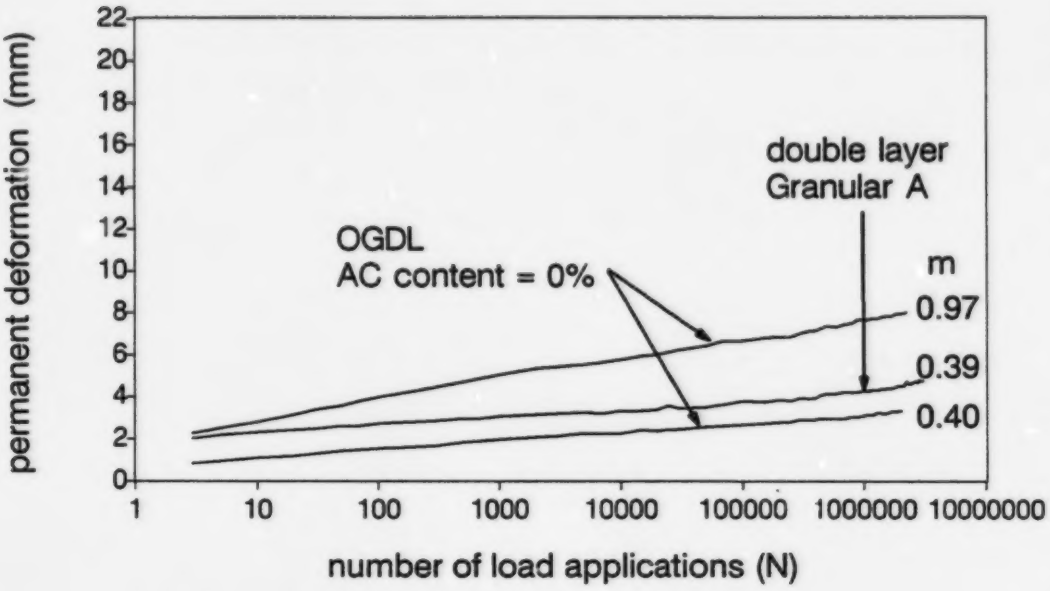


Figure 13 Load–deformation response from selected tests with Granular A subbase